

## TITLE OF THE INVENTION

### Liquid Epoxy Resin Composition and Semiconductor Device

5           This invention relates to a liquid epoxy resin composition which cures into a cured product having improved adhesion to the surface of silicon chips and especially photosensitive polyimide resins and nitride films, and stability against thermal shocks. It also relates to a  
10 semiconductor device which is sealed with the cured product of the liquid epoxy resin composition.

## BACKGROUND OF THE INVENTION

15           The trend toward smaller sizes, lighter weights and increased capabilities in electrical equipment has led to a shift in the dominant semiconductor mounting process from pin insertion to surface mounting. Progress of semiconductor devices toward a higher degree of integration  
20 entails the enlargement of dies having a size as large as 10 mm or more per side. For semiconductor devices using such large size dies, greater stresses are applied to the die and the sealant during solder reflow. Such stresses are problematic because separation occurs at the interface  
25 between the sealant and the die or substrate, the package cracks upon substrate mounting, and delamination and cracking occur after a thermal cycling test, leading to electrical failure.

## SUMMARY OF THE INVENTION

30           An object of the invention is to provide a liquid epoxy resin composition which cures into a cured product that has improved adhesion to the surface of silicon chips and especially photosensitive polyimide resins and nitride  
35 films, does not deteriorate under hot humid conditions as encountered in PCT (120°C/2.1 atm), and does not peel or crack over several hundred cycles of thermal cycling between

-65°C and 150°C. Another object of the invention is to provide a semiconductor device which is sealed with the cured product of the liquid epoxy resin composition.

The invention pertains to a liquid epoxy resin composition comprising (A) a liquid epoxy resin, (B) an optional curing agent, (C) a curing accelerator, and (D) an inorganic filler. It has been found that by blending a suitable amount of (E) acrylic submicron particles of core-shell structure formed of polymers or copolymers comprising an alkyl acrylate and/or alkyl methacrylate as a monomeric component, preferably after uniformly pre-mixing the acrylic submicron particles with the liquid epoxy resin (A), there is obtained a liquid epoxy resin composition that is effectively adherent to the surface of silicon chips and especially photosensitive polyimide resins and nitride films and is fully resistant to thermal shocks, so that it is suited as a sealant for large die size semiconductor devices.

Acrylic particles of core-shell structure formed of a copolymer of alkyl acrylate and/or alkyl methacrylate are known as one component in semiconductor sealing compositions. It has been found that by previously melt mixing the acrylic particles with a liquid epoxy resin, it becomes possible to accomplish uniform dispersion of the acrylic particles in the composition, leading to efficient operation. Compounding of the acrylic particles leads to a liquid epoxy resin composition that is resistant to heat and stable against thermal shocks and hence, best suited as a sealant for large die size semiconductor devices.

In one aspect, the invention provides a liquid epoxy resin composition comprising

- (A) a liquid epoxy resin,
- (B) an optional curing agent,
- (C) a curing accelerator,
- (D) an inorganic filler, and
- (E) acrylic particles of core-shell structure formed of polymers or copolymers comprising an alkyl acrylate or

alkyl methacrylate or both as a monomeric component. The acrylic particles have an average particle size of 0.1 to 1.0  $\mu\text{m}$ , while the core has a glass transition temperature of up to  $-10^{\circ}\text{C}$ , and the shell has a glass transition

5 temperature of 80 to  $150^{\circ}\text{C}$ . The acrylic particles are blended in an amount of 0.5 to 20 parts by weight per 100 parts by weight of the liquid epoxy resin (A) or the liquid epoxy resin (A) and the curing agent (B) combined.

The composition is suitable for the sealing of  
10 semiconductor devices, especially flip-chip type semiconductor devices. Another aspect of the invention provides a semiconductor device, especially of the flip chip type, which is sealed with the liquid epoxy resin composition in the cured state.

#### 15 BRIEF DESCRIPTION OF THE DRAWING

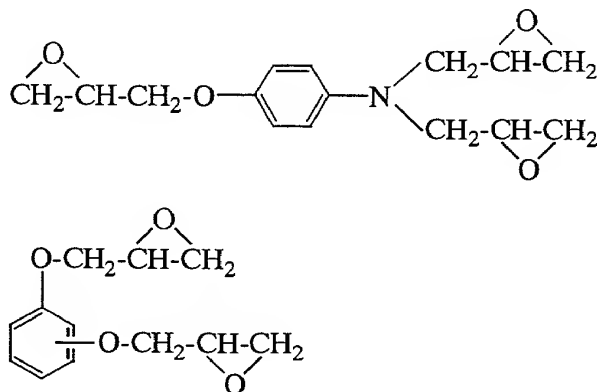
The only figure, FIG. 1 is a schematic view of a flip chip-type semiconductor device according to one embodiment of the invention.

#### 20 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Component (A) in the liquid epoxy resin composition is a liquid epoxy resin that is not critical with respect to molecular structure or molecular weight so long as it has at  
25 least two epoxy groups per molecule. Illustrative examples include bisphenol-type epoxy resins such as bisphenol A epoxy resin and bisphenol F epoxy resin, novolac-type epoxy resins such as phenolic novolac epoxy resin and cresol novolac epoxy resin, triphenolalkane-type epoxy resins such  
30 as triphenolmethane epoxy resin and triphenolpropane epoxy resin, phenylalkyl-type epoxy resins, biphenylalkyl-type epoxy resins, stilbene-type epoxy resins, naphthalene-type epoxy resins, biphenyl-type epoxy resins and cyclopentadiene-type epoxy resins. These epoxy resins may  
35 be used singly or as mixtures of two or more thereof.

The liquid epoxy resin used in the liquid epoxy resin composition may be any desired one which has at least two epoxy groups per molecule and is liquid at room temperature (e.g., 25°C). Bisphenol-type epoxy resins such as bisphenol

5 A epoxy resin or bisphenol F epoxy resin are especially preferred. Such epoxy resins may have added thereto epoxy resins of the following structures, provided such addition does not adversely affect penetrability of the sealant.



10 The liquid epoxy resin preferably has a total chlorine content of not more than 1,500 ppm, and especially not more than 1,000 ppm. When chlorine is extracted from the epoxy resin with water at an epoxy resin concentration of 50% and a temperature of 100°C over a period of 20 hours, the water-

15 extracted chlorine content is preferably not more than 10 ppm. At a total chlorine content of more than 1,500 ppm or a water-extracted chlorine level of more than 10 ppm, the reliability of the sealed semiconductor device, particularly in the presence of moisture, may be compromised.

20 In the liquid epoxy resin composition of the invention, the liquid epoxy resin (A) can be cured by the curing accelerator (C), obviating the need for a curing agent, in which case the composition is a self-condensing composition. However, if necessary, the composition can be cured by

25 including a curing agent in the composition to formulate a phenolic resin-curable, acid anhydride-curable or amine-curable composition, for example.

The curing agent (B) is optional in the inventive composition. Any known curing agent may be employed without particular limitation with respect to characteristics such as molecular structure and molecular weight, provided the compound has at least two functional groups capable of reacting with the epoxy groups on the epoxy resin (A), e.g., phenolic hydroxyl groups, amino groups, and acid anhydride groups (at least one acid anhydride group). For example, phenolic resins having at least two phenolic hydroxyl groups per molecule may be used for this purpose. Illustrative examples include novolac-type phenolic resins such as phenolic novolac resin and cresol novolac resin, xylylene-modified novolac resins such as p-xylylene-modified novolac resin, m-xylylene-modified novolac resin and o-xylylene-modified novolac resin, bisphenol-type phenolic resins such as bisphenol A resin and bisphenol F resin, biphenyl-type phenolic resins, resol-type phenolic resins, phenol aralkyl-type resins, biphenyl aralkyl-type resins, triphenolalkane-type resins such as triphenolmethane resin and triphenolpropane resin, and phenolic resins which are polymers of any of the above; as well as naphthalene ring-containing phenolic resins and dicyclopentadiene-modified phenolic resins. Amine-type curing agents and acid anhydride-type curing agents are also useful.

Acid anhydrides are especially advantageous as the curing agent in liquid epoxy resin compositions adapted for use as underfill materials in flip chip-type semiconductor devices. Preferred acid anhydrides include those having on the molecule one or two aliphatic or aromatic rings, one or two acid anhydride groups (e.g., -CO-O-CO-), and about 4 to 25 carbons, and especially about 8 to 20 carbon atoms. Such acid anhydrides are exemplified by tetrahydrophthalic anhydride, methyltetrahydrophthalic anhydride, methylhexahydrophthalic anhydride, hexahydrophthalic anhydride, methylhymic anhydride, pyromellitic dianhydride, 3,4-dimethyl-6-(2-methyl-1-propenyl)-4-cyclohexane-1,2-dicarboxylic acid, 1-methyl-4-(1-methylethyl)-bicyclo-

[2.2.2]oct-5-ene-2,3-dicarboxylic acid, maleinized alloocimene, benzophenonetetracarboxylic dianhydride, 3,3',4,4'-biphenyltetracarboxylic dianhydride, bis(3,4-dicarboxyphenyl)ether dianhydride, bis(3,4-dicarboxyphenyl)-methane dianhydride and 2,2-bis(3,4-dicarboxyphenyl)propane dianhydride.

Other curing agents that may be used in the liquid epoxy resin composition of the invention include also carboxylic acid hydrazides such as dicyandiamide, adipic acid hydrazide and isophthalic acid hydrazide.

As already noted, the curing agent (B) is an optional component and need not be included in the liquid epoxy resin composition when the composition is cured as a self-polymerizing composition. However, in cases where a curing agent is used to cure the liquid epoxy resin composition, the curing agent should be included in an amount that is effective for curing the epoxy resin. If the curing agent is a phenolic resin, the molar ratio of phenolic hydroxyl groups in the curing agent per mole of epoxy groups on the epoxy resin is preferably from 0.5 to 1.5. Likewise, if the curing agent is an acid anhydride, the molar ratio of carboxyl groups derived from acid anhydride groups (-CO-O-CO-) in the curing agent per mole of epoxy groups on the epoxy resin is preferably from 0.5 to 1.5. At a molar ratio of less than 0.5, the curability may be inadequate. On the other hand, at a molar ratio greater than 1.5, unreacted acid anhydride may remain, possibly lowering the glass transition temperature. A molar ratio within a range of 0.8 to 1.2 is especially preferred. Alternatively, for substantially the same reasons, an acid anhydride curing agent may be incorporated such that the molar ratio of acid anhydride groups in the acid anhydride curing agent per mole of epoxy groups on the epoxy resin is in a range of preferably from 0.3 to 0.7, and most preferably from 0.4 to 0.6.

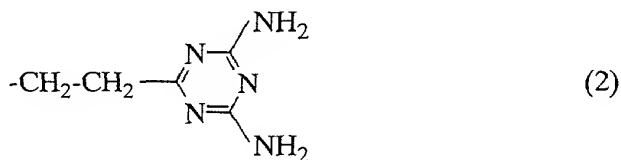
In the inventive composition, the curing or reaction accelerator (C) is blended for the purpose of curing the

epoxy resin (A) or accelerating curing reaction of the epoxy resin (A) with the curing agent (B). The curing accelerator is not critical as long as it can accelerate curing reaction. For example, one or more compounds selected from among  
5 imidazole compounds, tertiary amine compounds and organophosphorus compounds may be used as the curing accelerator. Of these, imidazole compounds and organophosphorus compounds are preferred.

10 The imidazole compounds that may be used include those of the following general formula (1).



In the formula (1), R¹ and R² are each independently a hydrogen atom or a substituted or unsubstituted monovalent hydrocarbon group of 1 to 12 carbon atoms, examples of which  
15 include alkyls, substituted alkyls and aryls such as methyl, ethyl, hydroxymethyl and phenyl. R³ is a substituted or unsubstituted monovalent hydrocarbon group of 1 to 12 carbon atoms, examples of which include alkyls, alkenyls and aryls such as methyl, ethyl, phenyl and allyl. R⁴ is a hydrogen  
20 atom; a substituted or unsubstituted monovalent hydrocarbon group of 1 to 12 carbon atoms, examples of which include alkyls, substituted alkyls and aralkyls such as methyl, ethyl, cyanoethyl and benzyl; or a group of formula (2) below.

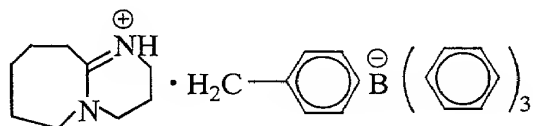


25

The substituted monovalent hydrocarbon groups mentioned above include hydroxy-substituted and cyano-substituted monovalent hydrocarbon groups.

Examples of suitable imidazole compounds include 2-methylimidazole, 2-ethylimidazole, 2-undecylimidazole, 2,4-dimethylimidazole, 2-heptadecylimidazole, 1,2-dimethylimidazole, 1,2-diethylimidazole, 2-phenyl-4-methylimidazole, 2,4,5-triphenylimidazole, 2-ethyl-4-methylimidazole, 2-phenylimidazole, 1-benzyl-2-phenylimidazole, 1-cyanoethyl-2-methylimidazole, 1-cyanoethyl-2-undecylimidazole, 1-benzyl-2-methylimidazole, 2-phenyl-4,5-dihydroxymethylimidazole, 2-aryl-4,5-diphenylimidazoles, 2,4-diamino-6-[2'-methylimidazolyl-(1)']-ethyl-S-triazine, 2,4-diamino-6-[2'-ethyl-4'-methylimidazolyl-(1)']-ethyl-S-triazine, the isocyanuric acid addition product of 2,4-diamino-6-[2'-methylimidazolyl-(1)']-ethyl-S-triazine, and 2-phenyl-4-methyl-5-hydroxymethylimidazole. Of the above imidazole compounds, 2-phenyl-4-methyl-5-hydroxymethylimidazole, 2-phenyl-4,5-dihydroxymethylimidazole, 2,4-diamino-6-[2'-ethyl-4'-methylimidazolyl-(1)']-ethyl-S-triazine, 2-methylimidazole, 2-ethyl-4-methylimidazole, 2-ethylimidazole, 1,2-dimethylimidazole, 1,2-diethylimidazole, 2,4-dimethylimidazole and 2-phenyl-4-methylimidazole are preferred.

Suitable tertiary amine compounds include amine compounds having alkyl or aralkyl substituents bonded to the nitrogen atom, such triethylamine, benzyldimethylamine, benzyltrimethylamine and  $\alpha$ -methylbenzyldimethylamine; cycloamidine compounds or organic acid salts thereof, such as 1,8-diazabicyclo[5.4.0]undec-7-ene and its phenol, octanoic acid and oleic acid salts; and salts or complex salts of cycloamidine compounds with quaternary boron compounds, such as the compound of the following formula.



Suitable organophosphorus compounds include triorganophosphines such as triphenylphosphine, tributylphosphine, tri(p-methylphenyl)phosphine, tri(nonylphenyl)phosphine, diphenyltolylphosphine and

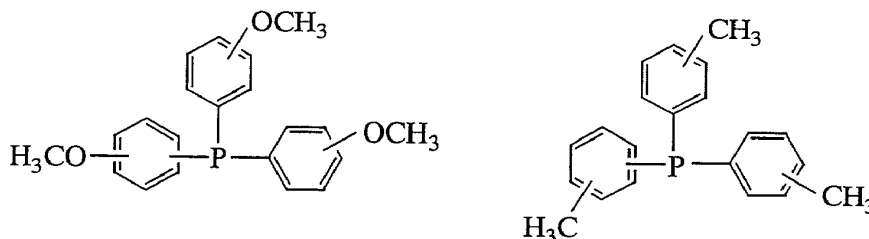


triphenylphosphine triphenylborane; and quaternary phosphonium salts such as tetraphenylphosphonium tetraphenylborate. Of these, organophosphine compounds of general formula (3) below are preferred.



In formula (3), R<sup>5</sup> is a hydrogen atom or an alkyl or alkoxy group of 1 to 4 carbon atoms. Examples of suitable alkyl groups include methyl, ethyl, propyl, isopropyl, butyl, isobutyl and tert-butyl. Examples of suitable alkoxy groups include methoxy and ethoxy. R<sup>5</sup> is preferably hydrogen or methyl.

Examples of formula (3) compounds include the following.



The curing accelerator may be blended as such, but preferably in microcapsule form. Since microcapsules containing the curing accelerator, typically an imidazole compound or an organophosphorus compound are more stable at high temperatures, the epoxy resin composition even loaded with a large amount of an inorganic filler is given a low viscosity enough to penetrate into narrow gaps, by heating the semiconductor device at a high temperature. Then the composition is a sealant which is effective especially as an underfill material in flip chip-type semiconductor devices having large size dies.

The microcapsules employed in the invention use as the shell material a polymer composed of (meth)acrylic monomers such as C<sub>1-8</sub> alkyl esters of acrylic acid, itaconic acid,

methacrylic acid or crotonic acid, or C<sub>1-8</sub> alkyl esters of the same type in which the alkyl groups have substituents such as allyl groups; monofunctional monomers such as styrene, α-methylstyrene, acrylonitrile, methacrylonitrile or vinyl acetate; and polyfunctional monomers such as ethylene glycol di(meth)acrylate, polyethylene glycol di(meth)acrylate, divinylbenzene, bisphenol A di(meth)acrylate and methylenebis(meth)acrylamide. The imidazole compound and/or organophosphorus compound serving as the catalyst is enclosed within the polymer. Of the above polymers, polymers of (meth)acrylic monomers are preferred.

A variety of methods may be used to produce the above-described microcapsules containing an imidazole compound and/or organophosphorus compound as the curing catalyst (or curing accelerator). The use of a method known to the art, such as suspension polymerization or emulsion polymerization, is advantageous for the efficient production of microcapsules of good sphericity.

To obtain what would normally be considered a high-concentration microencapsulated catalyst, based on the molecular structure of the catalyst, the above-described monomer is used in an overall amount of preferably about 10 to 200 parts by weight, more preferably 10 to 100 parts by weight, and most preferably 20 to 50 parts by weight, per 10 parts by weight of the curing catalyst. Less than 10 parts by weight of the monomer may be difficult to impart sufficient latency. On the other hand, the use of more than 200 parts by weight of the monomer lowers the proportion of catalyst, which may make it necessary to use a large amount of microencapsulated catalyst to achieve sufficient curability and can therefore be economically undesirable.

The microcapsules produced by the foregoing process typically have an average particle size of 0.5 to 15 μm, preferably 1 to 10 μm, and most preferably 2 to 7 μm. The maximum particle size is preferably no greater than 50 μm, and most preferably no greater than 20 μm. At an average

particle size of less than 0.5  $\mu\text{m}$ , the microcapsules may be too small in diameter or too large in specific surface area, the incorporation of a large amount of microcapsules in the composition may increase the viscosity thereof, and the catalyst may have insufficient latency. On the other hand, at an average particle size greater than 15  $\mu\text{m}$ , dispersion in the resin component may become non-uniform, leading to a decline in the reliability, in addition to which the microcapsules may be so large as to cause gate obstruction during molding.

The microencapsulated catalyst used herein preferably has a performance such that, when 1 g of the curing catalyst-containing microcapsules is measured out and mixed into 30 g of o-cresol, the mixture is left to stand at 30°C for 15 minutes, and the amount of catalyst that has dissolved out of the microcapsules is determined by gas chromatography, catalyst dissolution from the microcapsules into o-cresol corresponds to at least 70 wt% (i.e., 70 to 100 wt%) of the total amount of catalyst in the microcapsules. At less than 70 wt%, when the semiconductor device is molded using the epoxy resin composition, a molding time of at least 1 minute at 175°C becomes necessary, which may lower the efficiency of production. A dissolution of at least 75 wt% of the catalyst from the microcapsules is preferred.

The curing catalyst (or curing accelerator) is preferably included within the inventive composition in an amount of from 0.01 to 10 parts by weight, and more preferably 0.5 to 5 parts by weight, per 100 parts by weight of the liquid epoxy resin (A) when no curing agent (B) is included, or per 100 parts by weight of the liquid epoxy resin (A) and the curing agent (B) combined. The use of more than 10 parts by weight of the curing accelerator provides excellent cure, but tends to invite an undesirable loss in shelf stability. Notably the microencapsulated catalyst is preferably included in an amount of 1 to 15 parts, and more preferably 2 to 10 parts by weight per 100

parts by weight of the liquid epoxy resin (A) and the curing agent (B) combined.

As the inorganic filler (D), any inorganic filler known to be useful for lowering the expansion coefficient may be employed. Specific examples include fused silica, crystalline silica, alumina, boron nitride, aluminum nitride, silicon nitride, magnesia and magnesium silicate. Of these, spherical fused silica is desirable for achieving low viscosity and high penetration.

When the liquid epoxy resin composition is used as a potting material, the inorganic filler desirably has an average particle size of 2 to 20  $\mu\text{m}$  and a maximum particle size of preferably up to 75  $\mu\text{m}$ , more preferably up to 50  $\mu\text{m}$ . A filler with an average particle size of less than 2  $\mu\text{m}$  may provide an increased viscosity and cannot be loaded in large amounts. An average particle size of more than 25  $\mu\text{m}$  means the inclusion of a more proportion of coarse particles which will catch on lead wires, causing voids.

The amount of the filler included in the composition is in a range of preferably 100 to 600 parts by weight per 100 parts by weight of the epoxy resin (A) and the optional curing agent (B) combined or per 100 parts by weight of the epoxy resin (A), the optional curing agent (B) and an optional flexibilizer (to be described later) combined. At less than 100 parts by weight, the expansion coefficient tends to be too large, which may cause cracks to form in a thermal cycling test. On the other hand, at more than 600 parts by weight, the viscosity rises, which may bring about a decline in flow.

To obtain a sealant for underfilling which exhibits both improved penetration and a lower linear expansion, it is advantageous to include a filler having an average particle size at most about one-tenth as large and a maximum particle size at most one-half as large as the size of the gap between the substrate and chip in a flip chip semiconductor device. The amount of such filler included in

the sealant is in a range of preferably 100 to 400 parts by weight, and especially 150 to 250 parts by weight, per 100 parts by weight of the epoxy resin (A) and the curing agent (B) combined. At less than 100 parts by weight, the expansion coefficient tends to be too large, which may cause cracks to form in a thermal cycling test. On the other hand, at more than 400 parts by weight, the viscosity rises, which may bring about a decline in the thin-film penetration properties. The inorganic filler typically has a maximum particle size of preferably up to 50  $\mu\text{m}$ , more preferably up to 45  $\mu\text{m}$ , and most preferably up to 30  $\mu\text{m}$ . The average particle size of the filler is generally up to 10  $\mu\text{m}$ , preferably from 0.5 to 10  $\mu\text{m}$ , more preferably from 1 to 5  $\mu\text{m}$ , and most preferably from 1 to 3  $\mu\text{m}$ . The maximum particle size and average particle size may be obtained by particle size distribution measurement involving laser diffraction analysis. The average particle size may be suitably determined as the weight average value, or median diameter.

In the practice of the invention, preliminary surface treatment of the inorganic filler with a coupling agent such as a silane coupling agent or a titanate coupling agent is advantageous for further improving the low moisture absorption, impact resistance and crack resistance of the cured product.

Suitable coupling agents are silane coupling agents including epoxy functional group-bearing alkoxysilanes such as  $\gamma$ -glycidoxypropyltrimethoxysilane,  $\gamma$ -glycidoxypropylmethyldiethoxysilane and  $\beta$ -(3,4-epoxycyclohexyl)ethyltrimethoxysilane; amino functional group-bearing alkoxysilanes such as N- $\beta$ -(aminoethyl)- $\gamma$ -aminopropyltrimethoxysilane,  $\gamma$ -aminopropyltriethoxysilane and N-phenyl- $\gamma$ -aminopropyltrimethoxysilane; and mercapto functional group-bearing alkoxysilanes such as  $\gamma$ -mercaptopropyltrimethoxysilane. No particular limitation is imposed on the amount of coupling agent and method used in surface treatment.

The acrylic submicron particles of core-shell structure (E) are included in the epoxy resin composition of the invention. It is essential that the acrylic particles of core-shell structure be formed of polymers or copolymers comprising an alkyl acrylate and/or alkyl methacrylate as a monomeric component, the core have a glass transition temperature ( $T_g$ ) of up to  $-10^\circ\text{C}$ , the shell have a  $T_g$  of 80 to  $150^\circ\text{C}$ , and the acrylic particles have an average particle size of 0.1 to  $1.0\ \mu\text{m}$ . More particularly, the acrylic submicron particles are composite particles of the core-shell structure in which a rubbery polymer core is enclosed with a resinous shell. The core and the shell are formed of polymers or copolymers comprising an alkyl acrylate and/or alkyl methacrylate as a monomeric component. Examples of the alkyl group of the alkyl acrylate or alkyl methacrylate used as a monomeric component include those of 1 to about 8 carbon atoms, such as methyl, ethyl, propyl, isopropyl, butyl, isobutyl, tert-butyl, pentyl, hexyl, cyclohexyl, heptyl, 2-ethylhexyl, and octyl. Of these, lower alkyl groups of 1 to about 4 carbon atoms are preferred.

Another monomeric component can be included in the copolymer of which the core and shell are made. Exemplary other monomers include acrylic acid monomer, methacrylic acid monomer, substituted alkyl acrylates or methacrylates in which the alkyl groups of the above-described alkyl acrylates or methacrylates have substituted thereon alkenyl groups (e.g., vinyl and allyl) or functional groups (e.g., epoxy, carboxyl and hydroxyl), such as glycidyl (meth)acrylate, carboxyethyl (meth)acrylate, and hydroxyethyl (meth)acrylate, acrylonitrile, methacrylonitrile, aromatic ring-bearing olefin monomers such as styrene and  $\alpha$ -methylstyrene, and dienic monomers capable of forming rubbery elastomers such as butadiene and isoprene. Illustrative are acrylic submicron particles of the core-shell structure in which the core is made of a rubbery polymer or copolymer containing at least butyl

methacrylate as a monomeric component while the shell is made of a resinous polymer or copolymer containing at least methyl methacrylate as a monomeric component or a resinous copolymer containing at least methyl methacrylate and a substituted alkyl acrylate or methacrylate having a functional group such as carboxyl, epoxy or hydroxyl substituted on its alkyl portion, as monomeric components.

In the acrylic submicron particles, the acrylic polymers of which the core and shell are made usually have a number average molecular weight of about 100,000 to 800,000, especially about 20,000 to 600,000. Also in the acrylic submicron particles, the core has a Tg of up to  $-10^{\circ}\text{C}$ , and the shell has a Tg of 80 to  $150^{\circ}\text{C}$ . Particles prepared and adjusted to be spherical through emulsion polymerization are preferred. If the Tg of the core is higher than  $-10^{\circ}\text{C}$ , acrylic particles have a higher modulus of elasticity and do not withstand thermal shocks. If the Tg of the shell is lower than  $80^{\circ}\text{C}$ , acrylic particles are soft and agglomerate to preclude uniform dispersion during melt mixing. If the Tg of the shell is higher than  $150^{\circ}\text{C}$ , acrylic particles are hard and fail to exert the desired effect under thermal shocks. With respect to the size of acrylic particles, they have an average particle size of 0.1 to  $1.0\text{ }\mu\text{m}$  and a maximum particle diameter of up to  $10\text{ }\mu\text{m}$ , and preferably an average particle size of 0.3 to  $0.7\text{ }\mu\text{m}$  and a maximum particle diameter of up to  $5\text{ }\mu\text{m}$ . Particles with an average particle size of less than  $0.1\text{ }\mu\text{m}$  have a large specific surface area so that the composition may have an increased viscosity to obstruct working. An average particle size of more than  $1.0\text{ }\mu\text{m}$  leads to an unsatisfactory island-in-sea structure, failing to provide resistance to thermal shocks. The acrylic submicron particles bear on surfaces functional groups which are preferably carboxyl, epoxy or hydroxyl groups.

Such acrylic submicron particles of the core-shell structure are commercially available, for example, under the trade name of Stapharoid from Takeda Chemical Industries Ltd.

5           The amount of the acrylic submicron particles (E) added is 0.5 to 20 parts, desirably 1.0 to 10 parts by weight per 100 parts by weight of the liquid epoxy resin (A) and the curing agent (B) combined (or 100 parts by weight of the liquid epoxy resin (A) if the curing agent is absent).

10       Less than 0.5 part of acrylic particles fails to provide satisfactory thermal shock resistance whereas inclusion of more than 20 parts of acrylic particles increases the viscosity of the composition, which becomes difficult to work with.

15           With respect to the addition of the acrylic particles (E), it is desirable to previously melt mix the acrylic particles with a part or all of the liquid epoxy resin (A) before the premix is compounded with the remaining components. The melt mixing method includes blending  
20       appropriate proportions of the liquid epoxy resin and the acrylic particles and melt mixing them while heating at a temperature in the range of 80 to 150°C. Mixing under conditions outside these ranges often fails to achieve thorough mixing of acrylic particles with the epoxy resin,  
25       leaving a likelihood of agglomeration. The presence of primary particles at the end of mixing is desirable because considerable agglomeration precludes the composition from performing well. Any of well-known mixers and kneaders may be used in melt mixing.

30           The composition of the invention may include also a flexibilizer to lower stress. Suitable examples include silicone rubbers, silicone oils, liquid polybutadiene rubbers, and thermoplastic resins such as methyl  
35       methacrylate-butadiene-styrene copolymers. Preferably, the flexibilizer is a copolymer of an epoxy resin or phenolic resin with an organopolysiloxane, more specifically a copolymer prepared by the addition reaction of the alkenyl



groups within an alkenyl group-bearing epoxy resin or phenolic resin with the SiH groups (that is, hydrogen atoms bonded to silicon atoms) in an organohydrogenpolysiloxane of formula (4) below having 20 to 400, and preferably 40 to 200, silicon atoms and having 1 to 5, preferably 2 to 4, and most preferably 2, SiH groups per molecule.



10 In formula (4), R is a substituted or unsubstituted monovalent hydrocarbon group, "a" is a positive number from 0.002 to 0.1, "b" is a positive number from 1.8 to 2.2, and the sum a+b is from 1.81 to 2.3.

The monovalent hydrocarbon group represented by R preferably has 1 to 10 carbons, and especially 1 to 8 carbons. Illustrative examples include alkyl groups such as methyl, ethyl, propyl, isopropyl, butyl, isobutyl, tert-butyl, hexyl, cyclohexyl, octyl and decyl; alkenyl groups such as vinyl, allyl, propenyl, butenyl and hexenyl; aryl groups such as phenyl, xylyl and tolyl; aralkyl groups such as benzyl, phenylethyl and phenylpropyl; and halogenated monovalent hydrocarbon groups in which some or all of the hydrogen atoms on the hydrocarbon groups have been substituted with halogen atoms (e.g., chlorine, fluorine, bromine), such as chloromethyl, bromoethyl and trifluoropropyl.

Copolymers having one of the following structures are preferred.



5 letter n is an integer from 8 to 398, and preferably from 38  
to 198, p is an integer from 1 to 10, and q is an integer

10 siloxane units is 0 to 20 parts by weight, and preferably 2

to 15 parts by weight, per 100 parts by weight of the liquid epoxy resin (A) or 100 parts by weight of the liquid epoxy resin (A) and the curing agent (B) combined, whereby stress can be further reduced.

5           If necessary, the liquid epoxy resin composition may contain also other additives as long as they do not compromise the objects of the invention. Suitable additives include carbon-functional silanes for improving adhesion, antioxidants, waxes, pigments such as carbon black,  
10           colorants such as organic dyes, ion trapping agents, surfactants, and flame retardants such as brominated resins and antimony.

          The liquid epoxy resin composition of the invention may be prepared by the simultaneous or discrete stirring,  
15           melting, mixing or dispersion of the epoxy resin, curing accelerator and inorganic filler as well as optional components such as curing agent and flexibilizer, while carrying out heat treatment if necessary. Prior to this compounding step, the acrylic particles are preferably melt  
20           premixed with a portion or all of the epoxy resin as described above. No particular limitation is imposed on the apparatus used for mixing, stirring, dispersing and otherwise processing the mixture of components. Exemplary apparatus suitable for this purpose include an automated  
25           mortar, three-roll mill, ball mill and planetary mixer which is equipped with an agitator and a heater. Use can also be made of suitable combinations of these apparatuses.

          Preferably the liquid epoxy resin composition has a viscosity of less than about 10,000 poises at 25°C.

30           An ordinary molding method and ordinary molding conditions may be employed when sealing semiconductor devices with the inventive composition. It is preferable to carry out an initial hot oven cure at about 100 to 120°C for at least about 1/2 hour, followed by a subsequent hot oven  
35           cure at about 150°C for at least about 1/2 hour. Initial curing conditions below the above-mentioned temperature and time may result in void formation after curing, and

subsequent curing conditions below the temperature and time indicated above may yield a cured product having less than sufficient properties.

The semiconductor devices to be sealed with the inventive composition are typically flip chip-type semiconductor devices. Referring to FIG. 1, the flip chip-type semiconductor device includes an organic substrate 1 having an interconnect pattern side on which is mounted a semiconductor chip 3 over a plurality of intervening bumps 2. The gap between the organic substrate 1 and the semiconductor chip 3 (shown in the diagram as gaps between the bumps 2) is filled with an underfill material 4, and the lateral edges of the gap are sealed with a fillet material 5. The inventive composition is especially suitable in forming the underfill. When the inventive composition is used as an underfill material, the cured product preferably has an expansion coefficient of 20 to 40 ppm/°C below the glass transition temperature. Sealant used as the fillet material may be a conventional material known to the art. The use as the fillet of a liquid epoxy resin composition of the same general type as that described above is especially preferred, although the cured product in this case preferably has an expansion coefficient of 10 to 20 ppm/°C below the glass transition temperature.

#### EXAMPLE

Examples of the invention and comparative examples are given below by way of illustration, and are not intended to limit the invention.

#### Examples 1 to 4 and Comparative Examples 1 to 5

The components shown in Table 1 were blended to uniformity on a three-roll mill to give nine epoxy resin compositions. These epoxy resin compositions were examined by the following tests. The results are also shown in Table 1.

### Viscosity

The viscosity at 25°C was measured using a BH-type rotary viscometer at a rotational speed of 4 rpm.

### Gelation Time

5        The gelation time for the composition was measured on a hot plate at 150°C.

### Glass Transition Temperature (T<sub>g</sub>)

Using a sample of cured material measuring 5 × 5 × 15 mm, the glass transition temperature was measured with a thermomechanical analyzer at a heating rate of 5°C/min.

### Coefficients of Thermal Expansion

In the measurement of the glass transition temperature described above, the coefficient of thermal expansion below the glass transition temperature (CTE-1) was determined for a temperature range of 50 to 80°C, and the coefficient of thermal expansion above the glass transition temperature (CTE-2) was determined for a temperature range of 200 to 230°C

### PCT Delamination Test

20        A polyimide-coated 10 × 10 mm silicon chip was stacked on a 30 × 30 mm FR-4 substrate using spacers of approximately 100 μm thick, leaving a gap therebetween. An epoxy resin composition was introduced into the gap and cured. The assembly was then placed in a pressure cooker test (PCT) environment of 121°C and 2.1 atm for 168 hours. At the end of the test, the assembly was checked for delamination by C-SAM.

### Thermal shock test

A polyimide-coated 10 × 10 mm silicon chip was stacked on a 30 × 30 mm FR-4 substrate using spacers of approximately 100 μm thick, leaving a gap therebetween. An epoxy resin composition was introduced into the gap and cured. The assembly was then tested by thermal cycling between -65°C/30 minutes and 150°C/30 minutes. After 250, 500 and 750 cycles, the assembly was examined for peeling and cracks.

Table 1

Component (pbw)	Example				Comparative Example				
	1	2	3	4	1	2	3	4	5
RE410	16	16	34	80	43	40	80	43	16
MH700	50	50	50		50	50		50	50
SE8FC	150	150	150	150	150	150	150	150	150
KBM403	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Copolymer	2	2	2	2	2	2	2	2	2
Microencapsulated catalyst of 2E4MZ	5	5	3		5	5		5	5
2E4MZ			0.5						
2P4MHZ-PW				3			3		
AC3832/RE410(1/9) premix	30		10	20		4			
AC3355/RE410(1/9) premix		30							
Trial A/RE410(1/9) premix									30
AC3832								3	
Viscosity at 25°C (Pa·s)	41.2	69.5	42.5	98.3	35.2	38.2	88.5	36.3	43.2
Gelation time at 150°C (s)	71	68	58	85	74	60	93	75	74
Tg (°C)	140	138	128	137	142	141	138	133	124
CTE-1 (ppm/°C)	32	31	31	32	33	31	32	34	35
CTE-2 (ppm/°C)	108	105	106	95	110	108	97	104	107
PCT delamination test	no delami- nation	no delami- nation	no delami- nation	no delami- nation	delami- nated	delami- nated	no delami- nation	delami- nated	delami- nated
Failure (%) after thermal shock test									
250 cycles	0	0	0	0	100	15	100	45	100
500 cycles	0	0	0	0		100		100	
750 cycles	0	10	0	30					

## Components:

5 RE410: bisphenol A-type epoxy resin (Nippon Kayaku Co., Ltd.)

MH700: methyltetrahydrophthalic anhydride (New Japan Chemical Co., Ltd.)

SE8FC: spherical silica (Tokuyama Soda Co., Ltd.); maximum  
10 particle size ≤25 μm, average particle size 8 μm



methacrylate. Core's  $T_g \leq -20^\circ\text{C}$ . Shell's  $T_g = 120^\circ\text{C}$ .

Average particle size 3  $\mu\text{m}$ .

Note that "AC3832/RE410 (1/9) premix" means a premix of previously melt mixed AC3832 and RE410 in a weight ratio of 1/9, with like designations having the same meaning.

There has been described a liquid epoxy resin composition which cures into a cured product having improved adhesion to the surface of silicon chips and especially to photosensitive polyimide resins and nitride films and is thus best suited as a sealant for semiconductor devices having large size dies and especially of the flip chip type. These characteristics confer a very high reliability to semiconductor devices sealed with the inventive epoxy resin composition.

Japanese Patent Application No. 2000-351211 is incorporated herein by reference.

Although some preferred embodiments have been described, many modifications and variations may be made thereto in light of the above teachings. It is therefore to be understood that the invention may be practiced otherwise than as specifically described without departing from the scope of the appended claims.